Invention and Innovation in a Product-Centered Chemical Industry

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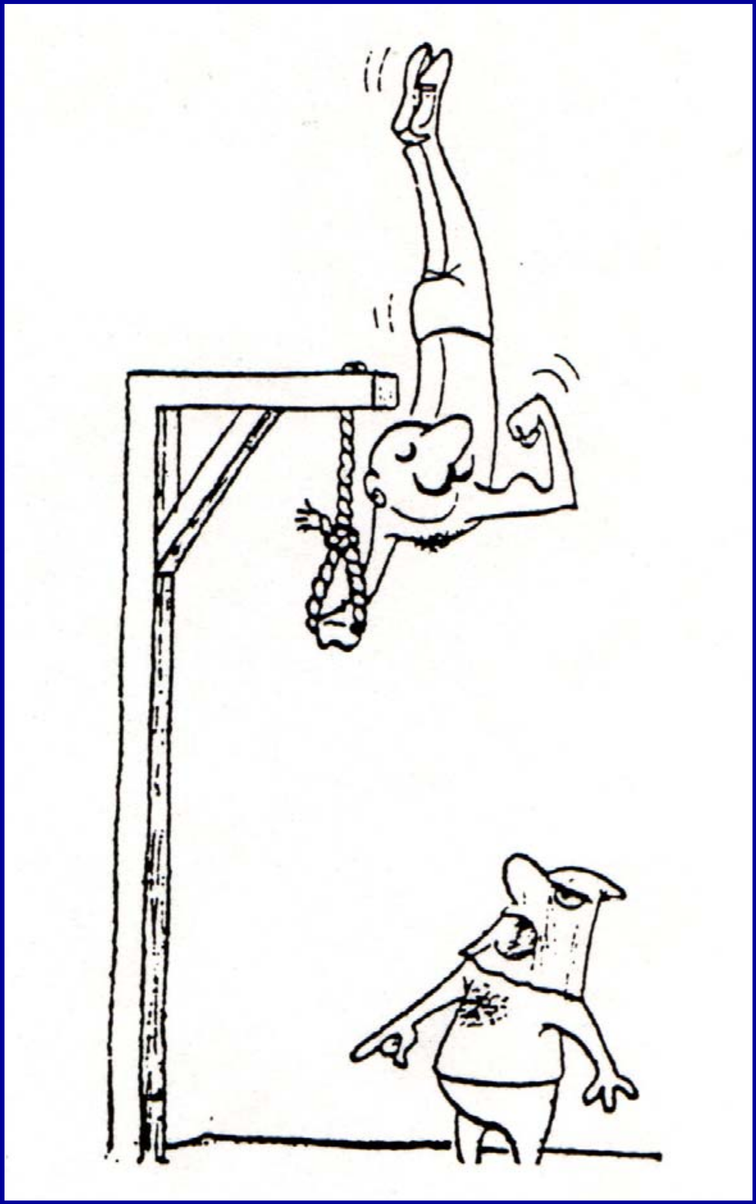
Massachusetts Institute of Technology

A WebCAST Lecture
October 26, 2004

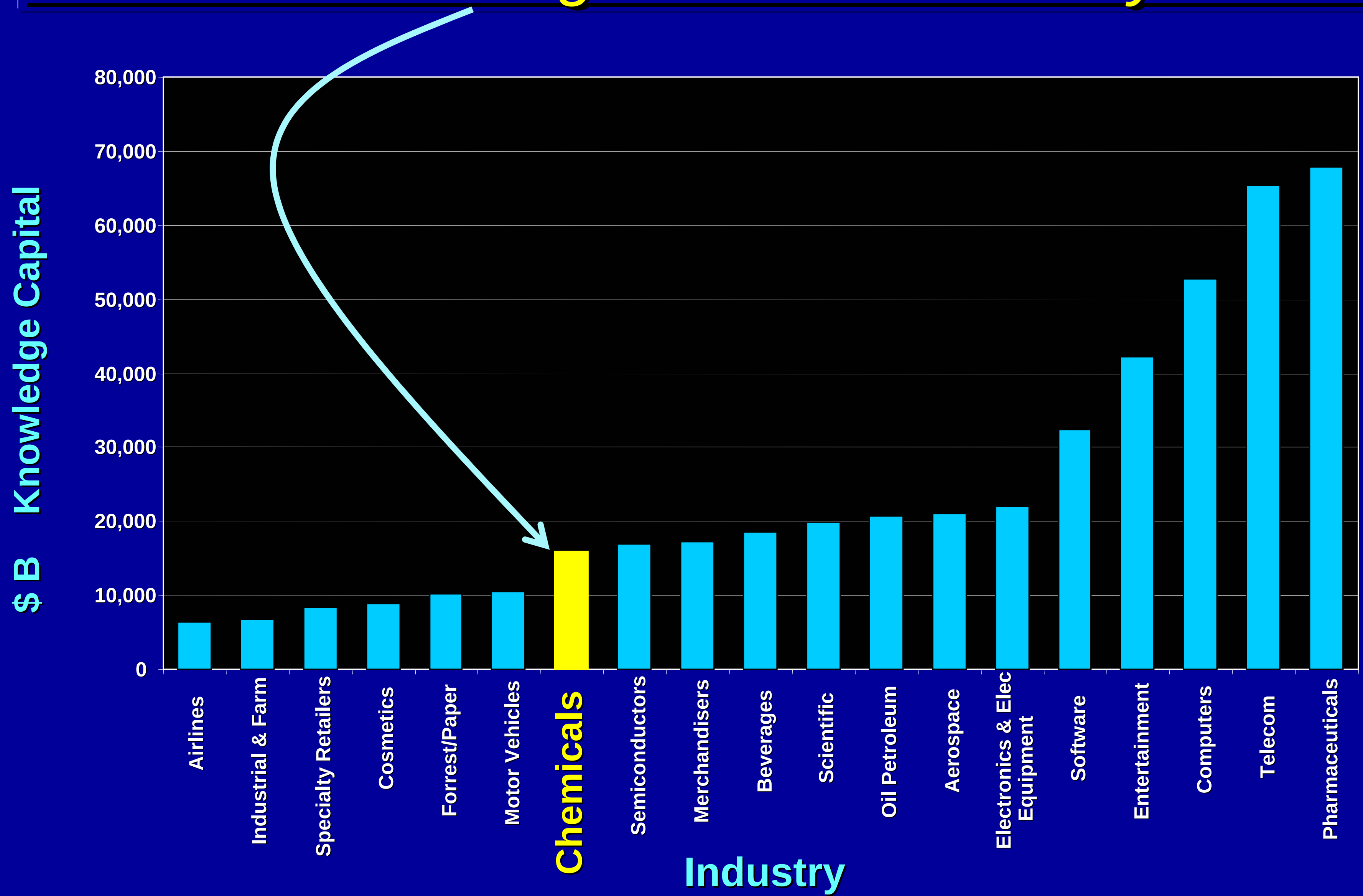
Outline



Part-1:

The State of and Trends in the Chemical Industry

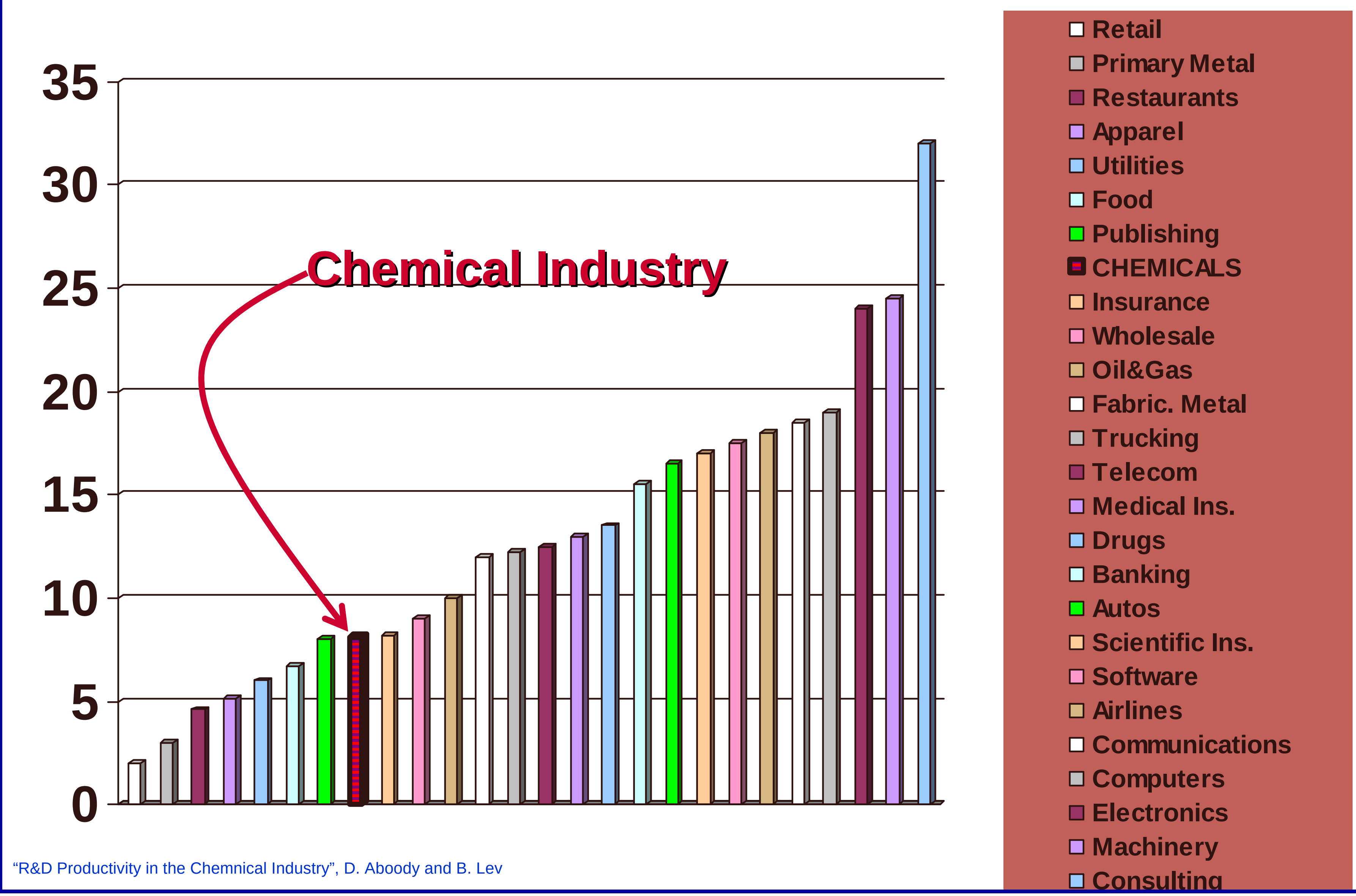
Fact-1: Chemical Industry IS NOT Valued as a Knowledge Intensive Industry



"R&D Productivity in the Chemnical Industry", D. Aboody and B. Lev

Knowledge-Driven Earnings

(average growth rate: 1990-1998)



"R&D Productivity in the Chemnical Industry", D. Aboody and B. Lev

Fact-2: Productivity in the Chemical Industry Lags Seriously Behind the National Manufacturing Productivity

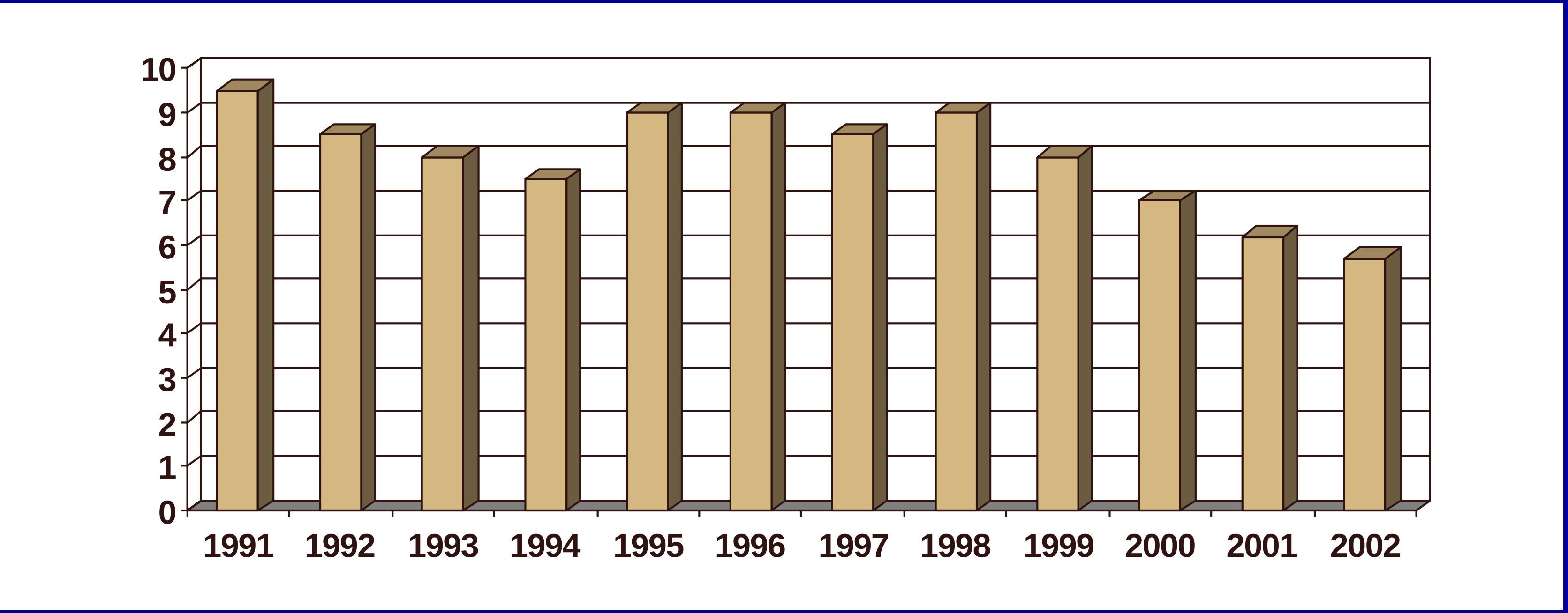
❖ Productivity (output per work hour; 1992=100):

- All Manufacturing :…………………. 156.8 ('01)
- Chemical industry:…………………. 123.7 ('01)

Fact-3: Capital Investment has been Sliding

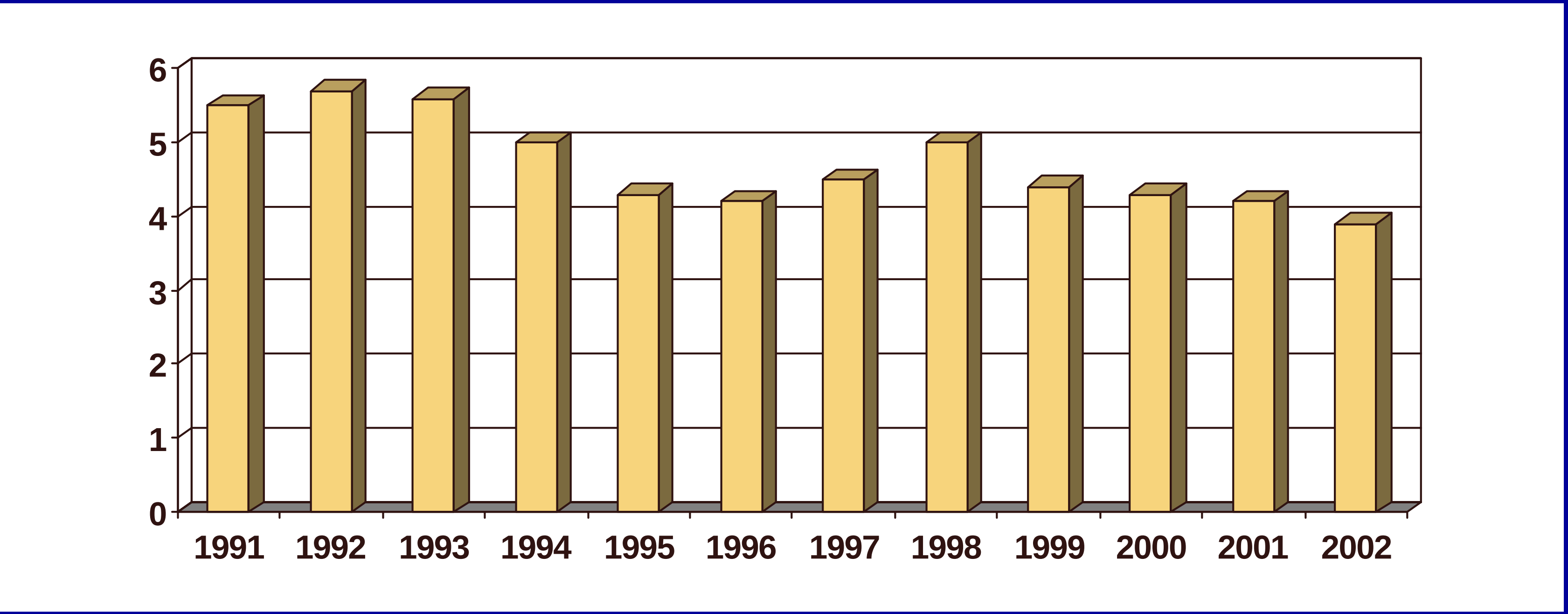
- Capital Spending (% of sales):

Downward trend



Fact-4: R&D Investment has been Sliding

- R&D Investment (% of sales):
  - Downward trend of total investment

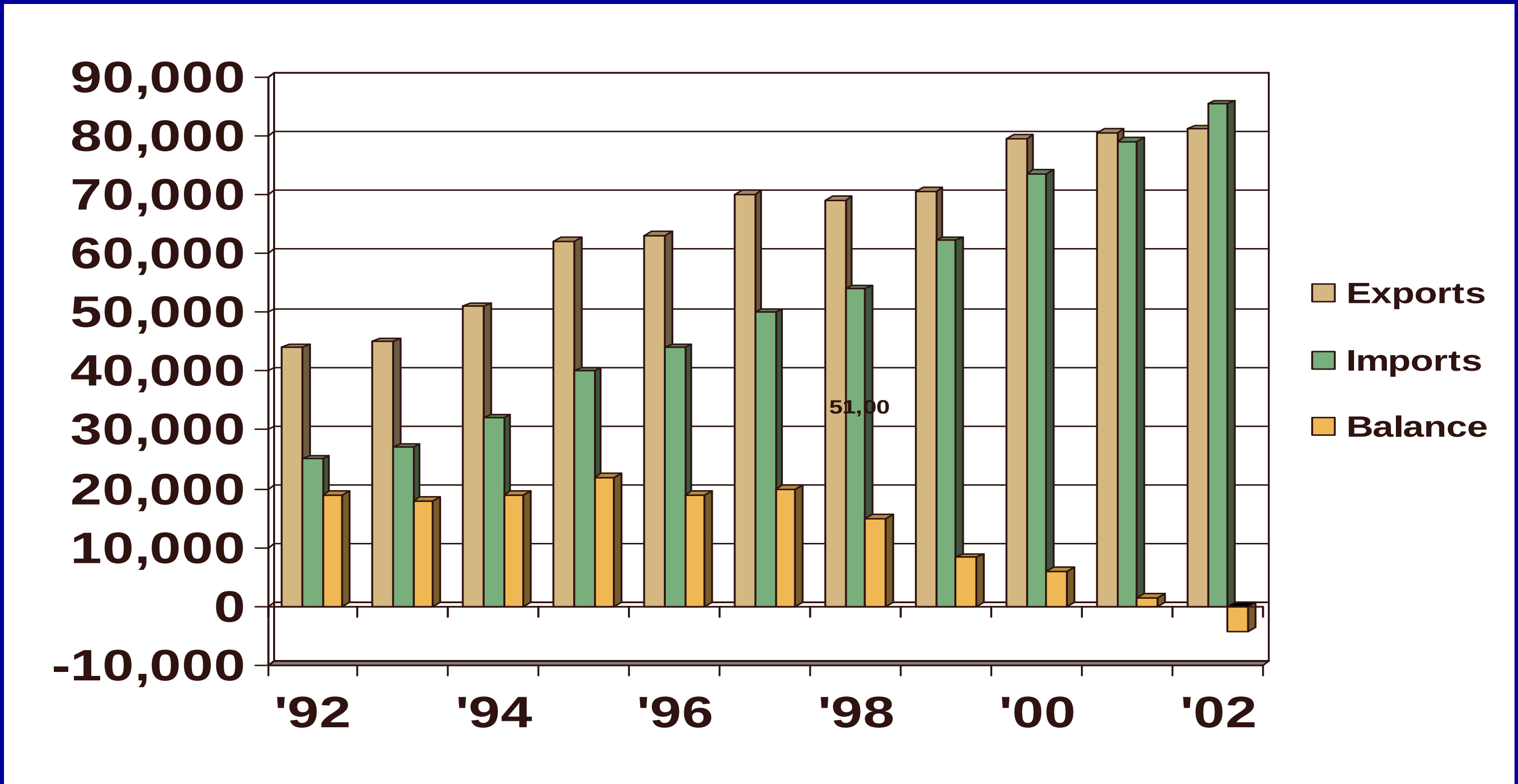


- Shift to “Focused”, Business-Unit Based, Product-Process Development Projects

Fact-5: *Negative Trade Balance*

❖ US Trade Balance:

Deteriorating since 1995. Deficit in 2002 (first time).

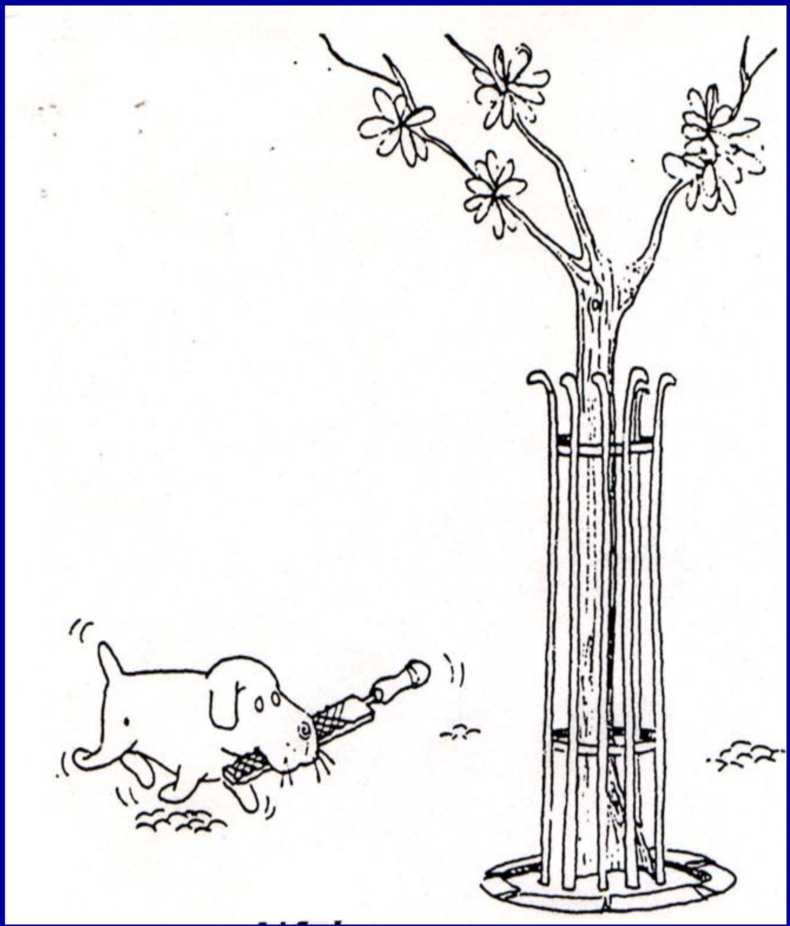


Fact-6: *Value Growth in Specialties and Products*

- Value: Value growth in specialties and products
  - Total chemicals.. 3.5% (annual change)
    - 1991 (318.6 billion $) 2002 (461.6 billion $)
  - Basic Chemicals..................................... 1.0%
    - 1991 (142.7 billion $) 2002 (152.1 billion $)
  - Specialty Chemicals.............................. 4.6%
    - 1991 (68.6 billion $) 2002 (107.6 billion $)
  - Life Sciences.. 6.7%
    - **1991 (70.1 billion $) 2002 (142.0 billion $)**
    - Pharmaceuticals……… 7.1%
      - **1991 (60.3 billion $) 2002 (128.3 billion $)**
    - Crop Protection………. 3.2%
      - **1991 (9.8 billion $) 2002 (13.7 billion $)**
  - Consumer Products.............................. 3.8%
    - 1991 (37.2 billion $) 2002 (51.1 billion $)
- Number of “new molecules” has been decreasing

Recent Trends (1991-2003): Summary

It seems that the Business Model of the “Diversified” Chemical company has been seriously weakened

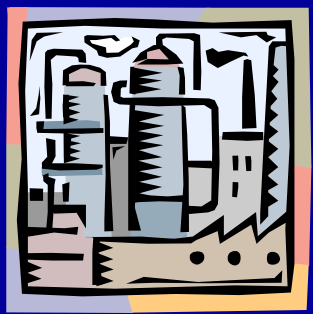


Part-2:

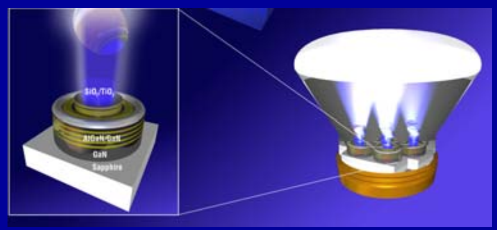
The Response of the Chemical Companies

Element-1: Fractionation of Diversified Chemical Companies

Diversified Chemical Companies



Production-Centric Company



Product-Centric Company

Customer Value-Centric Company

Increasing: Knowledge Content, Value, Economic Return

Element-2: Adjustment of Corporate Management Culture

Production-Centric: Dominate Market Share

Product-Centric: Dominate the Added-Value in a Product Chain

- Technology-Driven Marketing Culture: Culture of "*Innovation*"

Customer Value-Centric: Dominate the "Solutions-to-the-Customer" Channels

Different "Management Cultures" ARE NOT Commensurable but in CONFLICT with each other

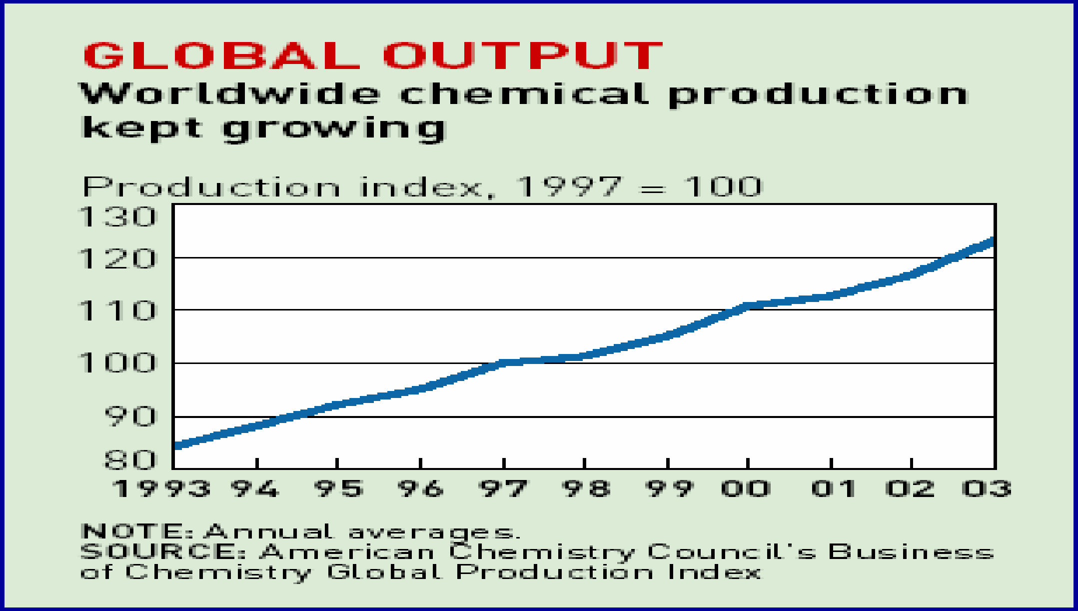
Element-3: *Adjustment in their Global Business Directions*

- The Demographics of Growth
- Market Areas of Growth
- From Process-Centered to Product-Centered Companies

The World Chemical Industry: Growth

1993 – 2003

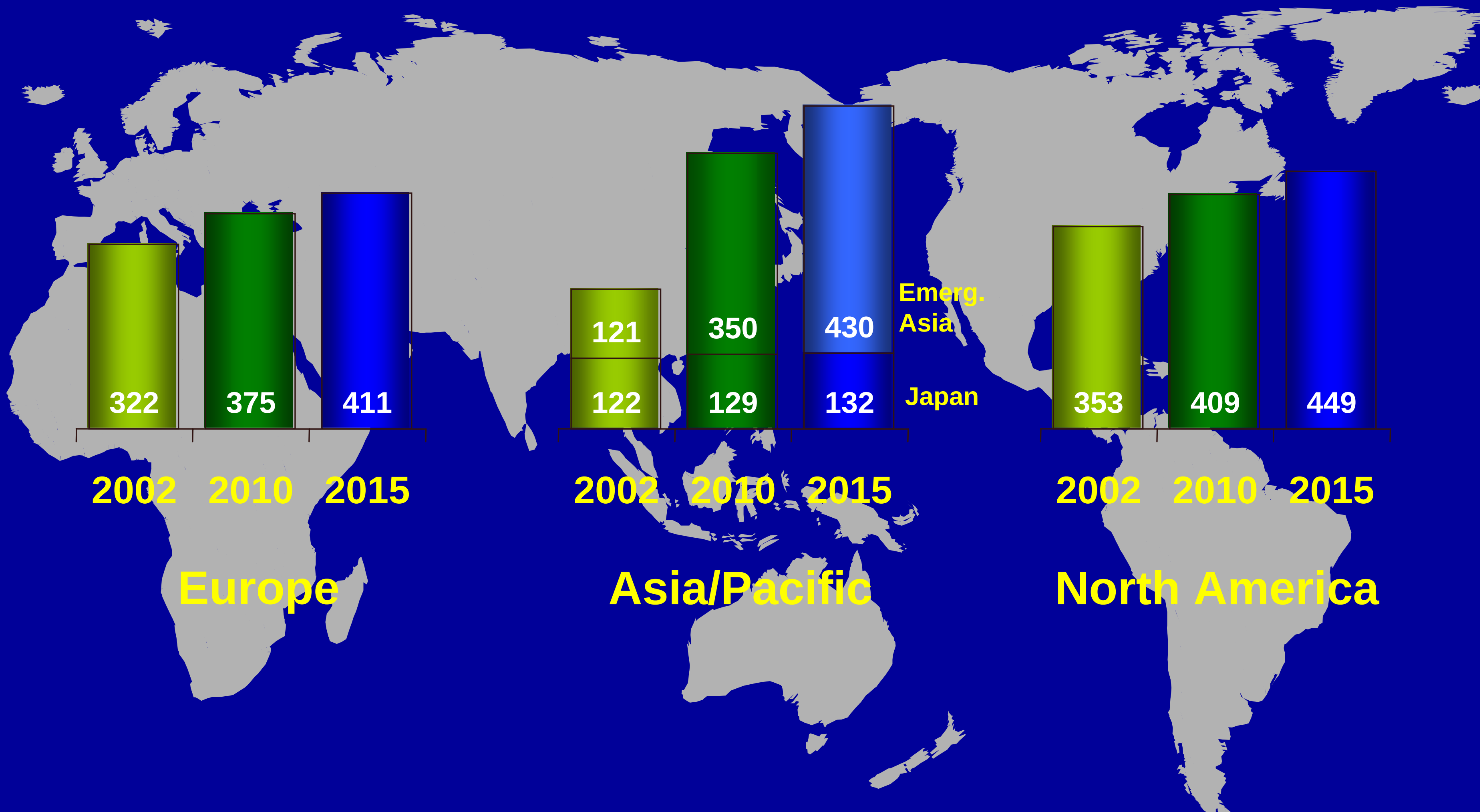
3.9 % per year



2004 – 2015: ……….. 2.3 – 2.5 % per year

Below the Gross World Product growth rate: 3.0 – 3.3 %

Chemical Demand by Region 2002 - 2015



source : BASF

Seven (7) Areas for New Business Creation

(METI: Nakagawa Report)

Market Size in 2010: About $ 2.8 tril

( ): Current Size

Info Home Appliances
$ 160 b ($ 100 b)

Robots
$ 16 b ($ 5 b)

Health, Welfare, (Devices, Services)
$ 700 b ($ 560 b)

Ecology, Energy, (Equipment, Services)
$ 700 b ($ 500 b)

Business Support Services
$ 1 tr ($ 700 b)

Fuel Cell
$ 10 b (Commercialization from Now)

Content (Materials, Fashion, Image, Music)
$ 130 B ($ 100 b)

*** Nakagawa Report -Toward a sustainable and competitive industrial structure.** Council on Economic and Fiscal Policy by Minister Nakagawa on May 19 2004.

Growing Global Markets of 2010

Size (> $10 billion), Rate (> 10%)	Size (< $10 billion), Rate (> 10%)
I&E, Device	
LCD ($ 90 bil), PDP ($ 50 bil) Digital Camera ($20 bil) Cell Phone ($ 400 bil) Optical Memory ($ 50 bil)	FED ($ 2 bil) OLED ($ 8 bil) Fullerene, Nanotube ($ 1 bil)
Ecology, Energy	
Amorphous Solar Cell ($ 30 bil) Lithium Ion Battery ($ 20 bil)	Biodegradable Polymer ($ 4.5 bil)
Transportation-related	
Hybrid Car ($ 13 bil)	Fuel Cell Car ($ 2.5 bil)
Medical, Security, Welfare	
Home Medical devices/ Systems ($ 110 bil)	Diagnostics Devices ($ 4.5 bil)

Tech & Industry of 21st Century: Excerpts from Nikkei, MRI,

Where Do the Companies See the Future Growth? (2004-2015)

- **Commodities:**
  - Primarily in Asia…….. 7-10 % per yr
- **Product-Oriented Chemicals and Materials:**
  - "Solutions-to-the-Customer" ………………….......… 10-15% per yr
    - Integration of technological services, chemicals, materials
  - Information/Electronics/Telecommunications............10-15%
    - Semiconductors; Displays; Inks; Specialty polymers; Energy devices
  - Medical …………………………………………........…. 6-10 %
    - Diagnostic, Packaging, Fabrics, Surgical supplies
  - Safety, Security, Protection ……………………..…… 6-10%
    - Diagnostic, Protective Materials
  - Life Amenities (Home, Office) ………………….…..…. 5-8 %
    - Materials/Components for cleaner, healthier environment; Personal care
  - Transportation…………………………………..…..…. 5-7 %
    - Material components and energy devices for automobiles & airplanes

Part-3:

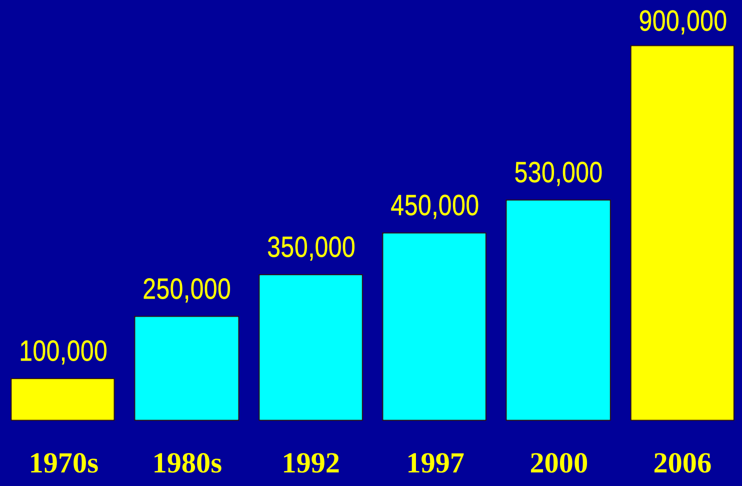
From a "Process-Centered" to a "Product-Centered" Chemical Industry

"Process-Centered" Company
(The Central Dogma of Chemical Engineering)

PROCESS DEVELOPMENT and DESIGN

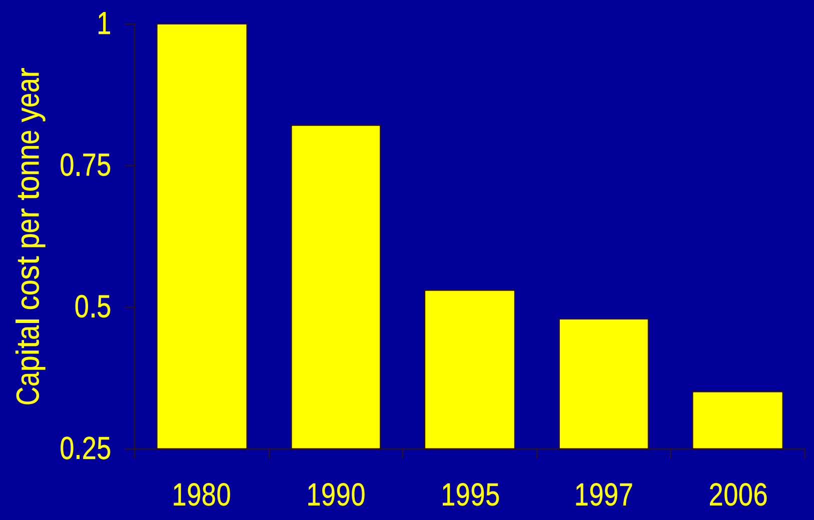
- Select Reaction Pathway(s)
- Design Catalysts; Select Solvents/Diluents/etc.
- Design reactors, separators, and other units
- Synthesize a Cost-Optimal Process with Satisfactory Safety, Operability, and Controllability Characteristics

Testimonial to the Success of "Process Systems Engineering"



PTA Plant Scale

PTA Plant Capital Productivity



Adapted from Jim Trainham

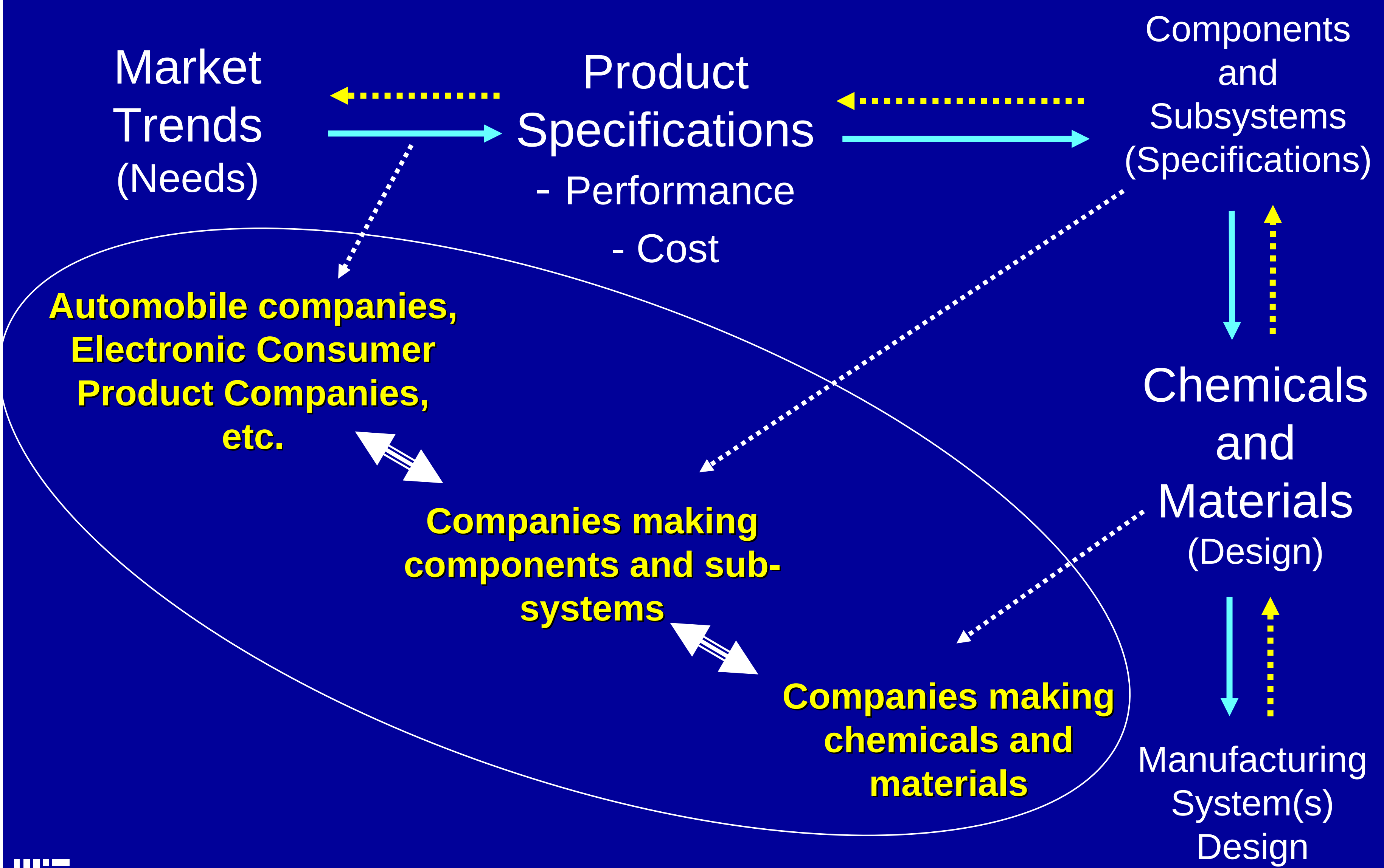
MCC's "Process-Centered" R&D

- Excellent R&D in Catalysis
- Integrated Process Development
- World-Class Process Systems Engineering
- Very effective Process Operations and Business Optimization

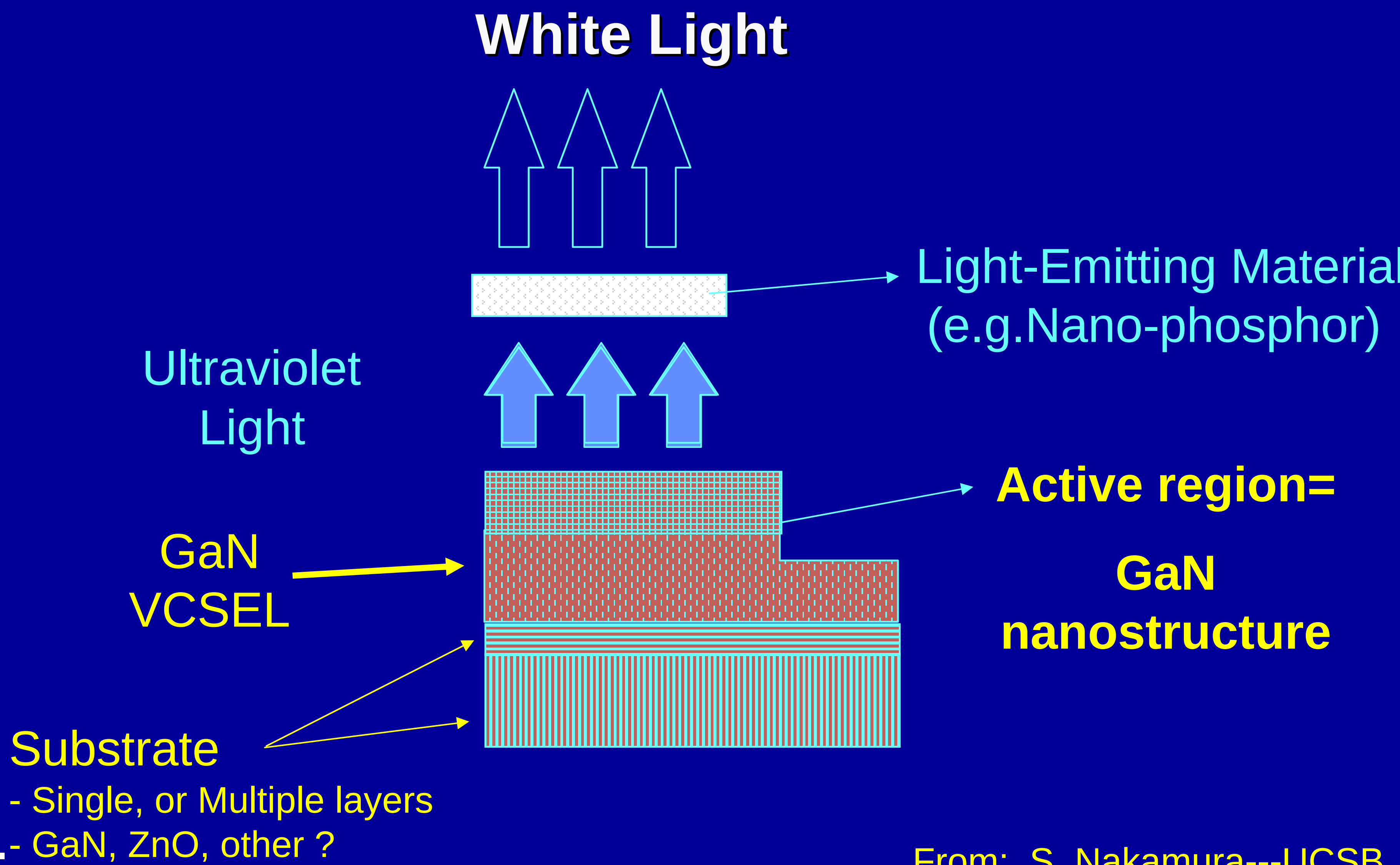
Unfortunately these capabilities
are not sufficient to provide today

DIFFERENTIATING COMPETITIVENESS

"Product-Centered" Chemical Industry
(The new Dogma for Chemical Engineering)



An Example: Solid-State Lighting and Displays



From: S. Nakamura---UCSB

An Example: *Solid-State Lighting and Displays*

- Markets (2010) ………………… $ 9.0 billion
  - Solid-Sate Lighting ………………………………$ 6.5 billion
  - Blue-NUV light emission …………………………$ 1.2
    - Next generation of DVD
    - Automobile lights
  - High-Frequency Devices …………………………$ 0.2
    - Microwave devices for ubiquitous communication
  - Dielectric Scintillator ………………………………$ 0.3
    - Dielectric devices; Diagnostic systems
  - Optical Devices …………………………………......... $ 0.5
    - Optical switching
    - Displays
  - Miscellaneous ………………………………… $ 0.3

MIT

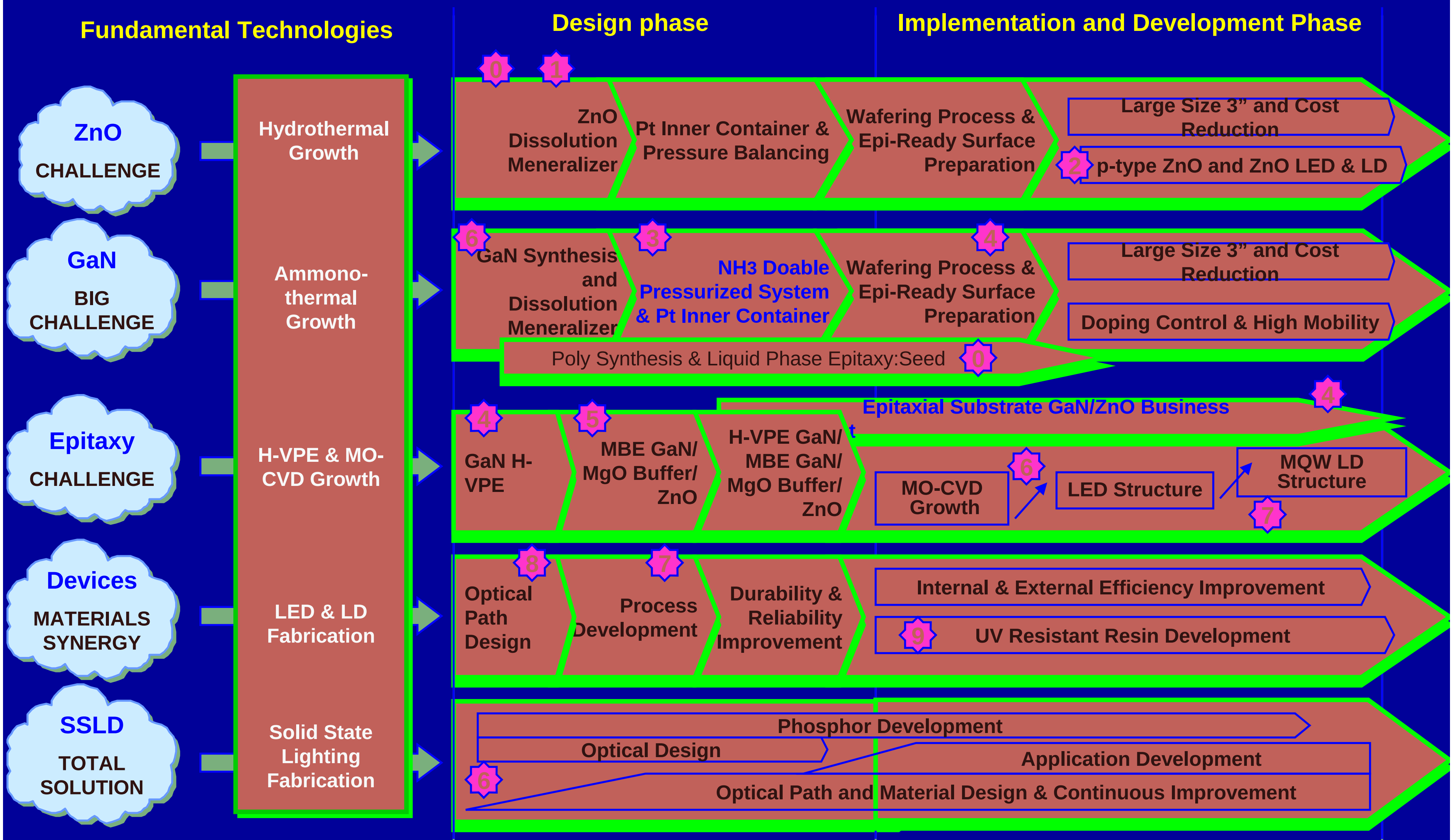
An Example: Solid-State Lighting and Displays

- Materials
  - Substrates for light emitting diodes (LED)
    - UV; Blue/Near UV
  - Light emitting materials
    - Organic (small molecules, polymers); Inorganic (phosphors); Hybrids
  - Supportive materials
    - Sealants; radical scavengers; etc.
- Processes
  - Continuous/Batch, Solid-Fluid processes for making the above materials
  - Discrete processes for making the devices

An Example: Solid-State Lighting and Displays

- “What” Materials to Make ?
  - Substrates:
    - GaN, ZnO, other? Single-layer; Multiple layers ?
  - Molecular structure and macroscopic morphological structure for
    - light-emitting materials
    - sealants
- “How” to Make the Materials ?
  - GaN and ZnO with very low dislocations’ density require technological breakthroughs
- Design of the LED devices for high-extraction
- Manufacturing the component elements

An Example: Solid-State Lighting and Displays (Partial Technology Road-Map)



An Example: *Solid-State Lighting and Displays*

- Can One Company do Everything?   NO
- How does a chemical company decide whether to address these market needs or not?
- How does a company decide what business position to take?
  - Materials only; Materials and components;
- How does a chemical company decide "what" to make, and thus what R&D to undertake?
- What are the requirements for the success of such an undertaking?

Part-4:

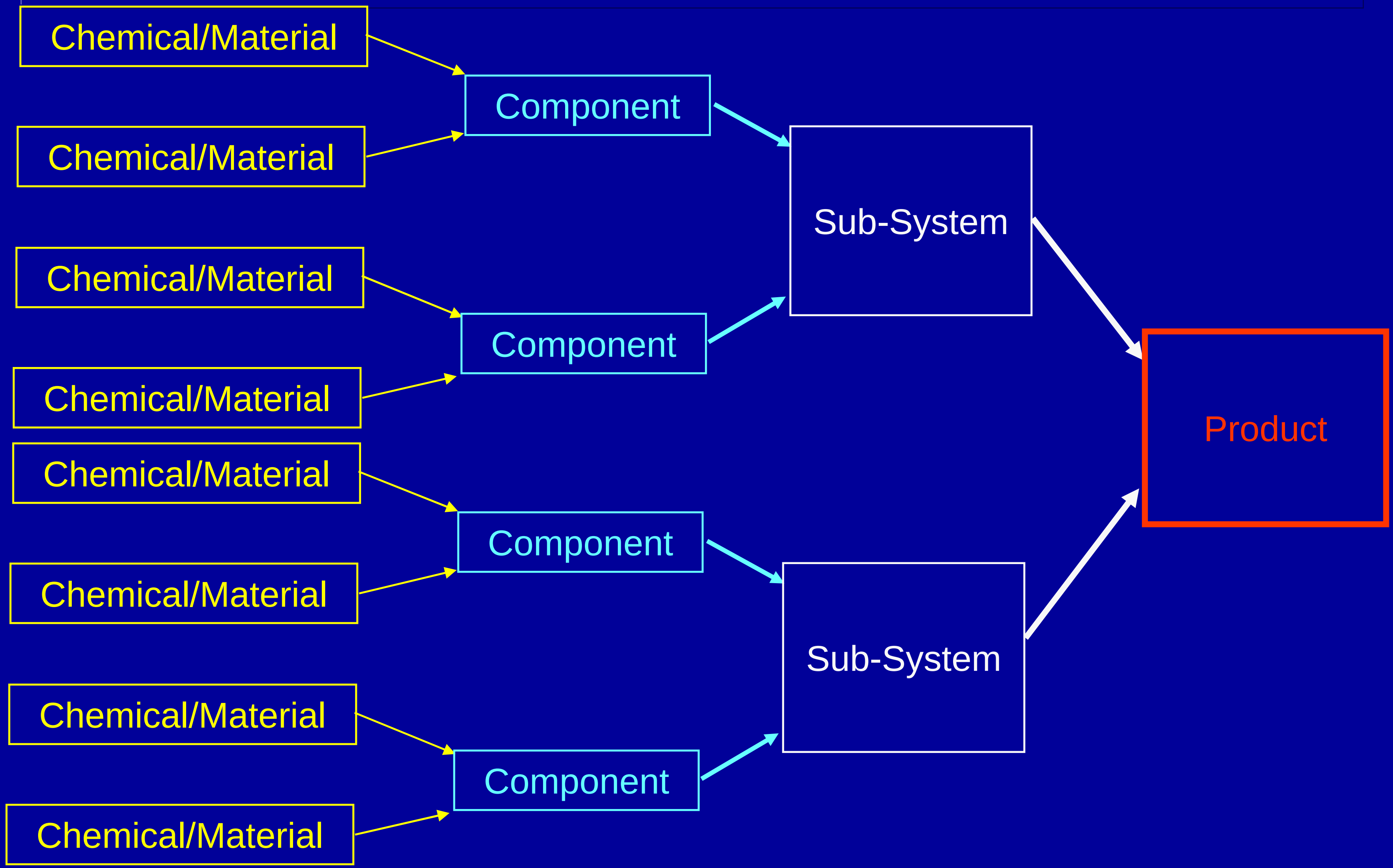
What Is and What Is Not Product Design in a "Product-Centered" Chemical Company?

Product Design

- Is NOT just the design of a Molecule with Desired Properties

- Is a complicated engineering system
  - With desired functions, and
  - At acceptable cost

The Product Supply-Chain (Also Defines the Technology Supply-Chain)



What Is Not

- The design of molecules for improvements in processing efficiencies, e.g.
  - Design of solvents, catalysts, diluents, etc.

- The design of “new” chemicals and materials intended as commodities, i.e.
  - Not clearly and directly related to specific consumer products

Example: *Design of Pharmaceuticals*

- A Pharmaceutical is not JUST a molecule, but an integrated design of the
  - Active ingredient molecule(s)
  - Formulation (chemical excipients' composition; physical form)
  - Delivery system

What Is

- Product-Process Development: Business to Business
  - Offer improved functionality and substantially reduce the total cost along the Product Supply-Chain, through
    - Product & process forward innovations, and
    - Improved total life-cycle cost

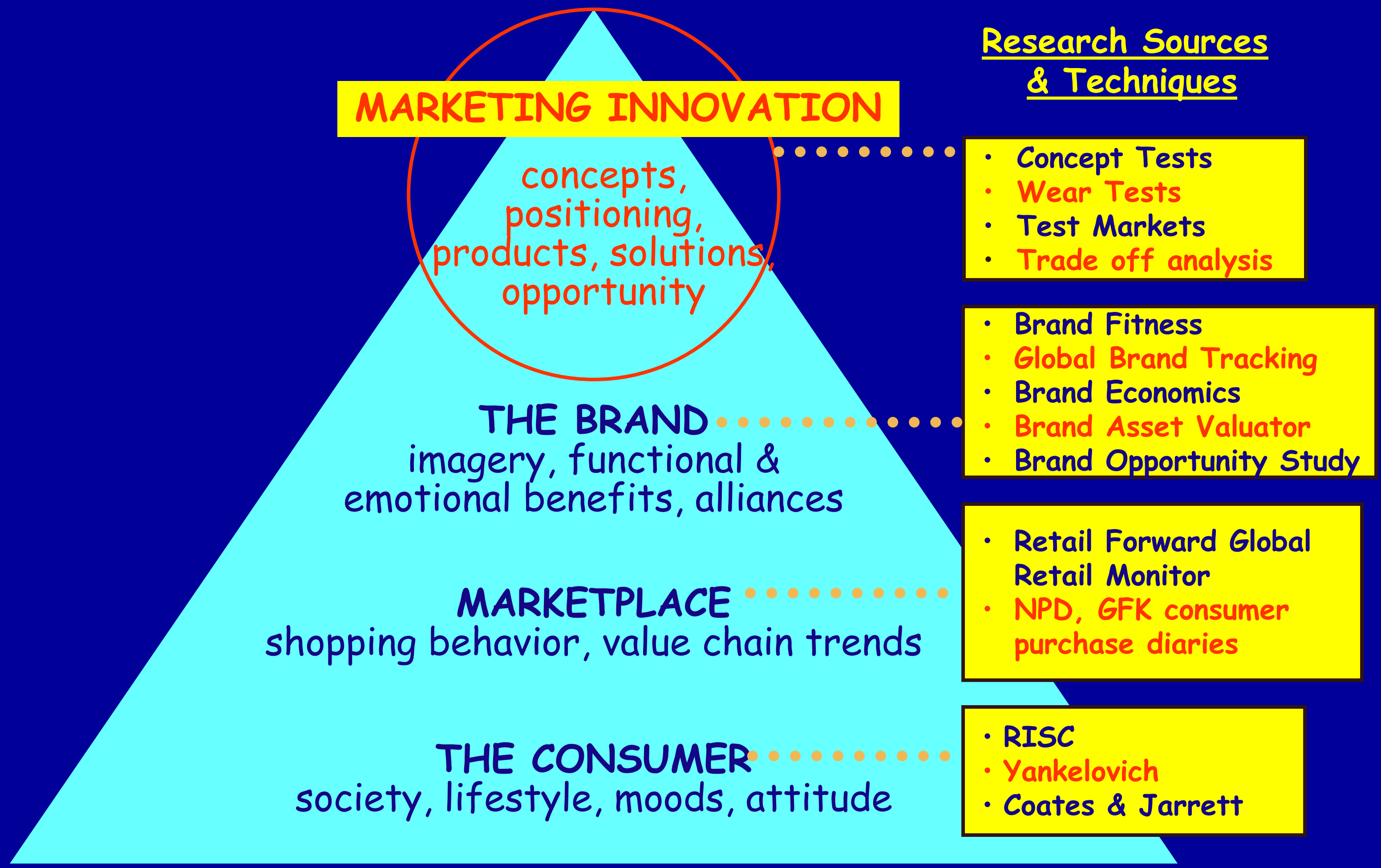
- Product Development: Business to Consumer
  - Deliver innovations the consumer values and for which he/she will pay.
  - Deliver functionality that exceeds consumer expectations and challenges their imagination.

Adapted from Jim Trainham

Examples: Materials for Displays (Business to Business)

- Replacement of Glass Substrates:
  - Consumer products: LCD, PDP, OLED, Paper Display.
    - Transparent, Conductive Polymers with Sufficient Mechanical Integrity, and etc. etc. etc.
    - Different specs for different products
    - Consolidation of films with glass replacement substrate
- Materials which consolidate several functions of multi-layered displays
  - LCD:
    - Color Filter Film-Polarizing Film-Protection Film
  - PDP:
    - EMI Shield Film-IR Absorption Film-Color Control Film-Antireflection Film
- Organic Thin Film Transistors (TFT) to replace Si-based films

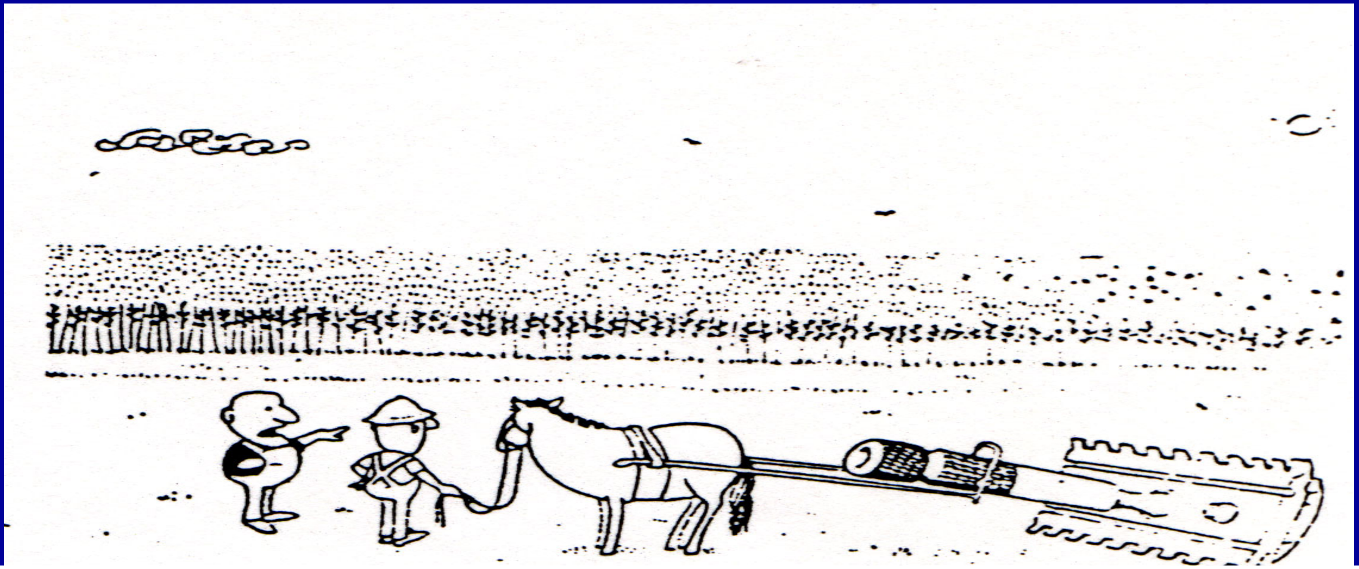
Example: Leather with Lycra (Business to Consumer)



From Jim Trainham

Part-5:

Implications on Industrial R&D from the Shift to a Product-Centered Industry



The Business Model of a "Product-Centered" Chemical Company

- The Chemicals/Materials will be
  - Targeted for specific Markets and Products
  - Produced in comparatively smaller quantities
- The Chemicals/Materials must offer Differentiating Value
  - "You cannot make money if you are dealing with the Materials Procurement Department of your customer"
    - Evolutionary improvements in cost and quality is not a differentiating advantage: Everybody does it
  - "You must try to Dominate (be the critical link) in the Product Supply-Chain"
    - **INNOVATION** is the Key

Implications from the Shift

- Many More Products than in the past
  - Smaller Sales Volumes ($ 10 to $150 million)
- R&TD Investment
  - High Return……………………..20-40 % per year
  - Higher Investment…………… 6 - 7 % of sales
  - Reduced Life-Cycle of Benefits: Continuous R&D Effort
  - Product-Oriented……………….3-4 years
- IP Strategy Defines the Technologies to be Developed
- Structure and Culture in the Management of R&D, i.e.
  - The Culture of "Entrepreneurship":
    - New Applications
    - New Markets
  - The spirit of the Venture start-up

The Need for Innovation: A Desperate Call from Industry

"Innovation":

The first successful Commercialization of an Invention

Innovation

- Is a Knowledge-Intensive Process
- Is a Business Activity
- Is much more than Discovery or Invention
- Focus on Execution

The Culture of Innovation

DIRECTION

1. A Different and Ambitious Corporate Vision
2. Alignment of Business and R&D Visions and Strategies
3. Integration of Marketing and R&D
   - IP Strategy and Business Positioning
   - The Role of the "Customer"

SPEED

4. Leveraging of Corporate Knowledge and Assets
   - Alliances with other Corporations
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5. An Effective and Ambitious R&D Organization
   - Flat Management Structure
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1. The New Vision

Reformation (Product & Services Oriented)

Mitsubishi Chemical Corporation will become a Dynamic, and Global

- *Product-Innovator*, and
- *The Preferred Solutions-Partner*

Rejuvenation (Ambition-Driven Strategy)

Corporate R&TD Aims at the Development of New Businesses in which MCC can be a Dominant Player, World-Wide

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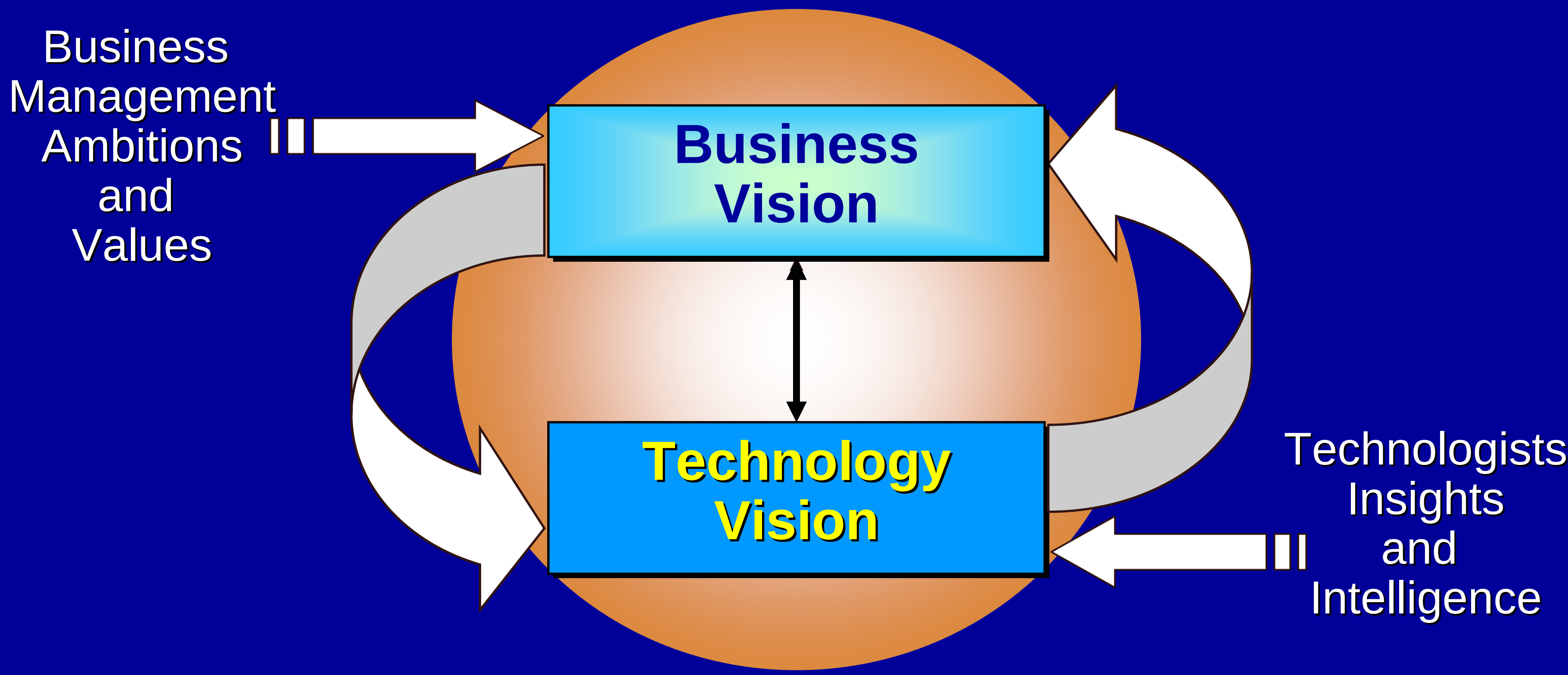
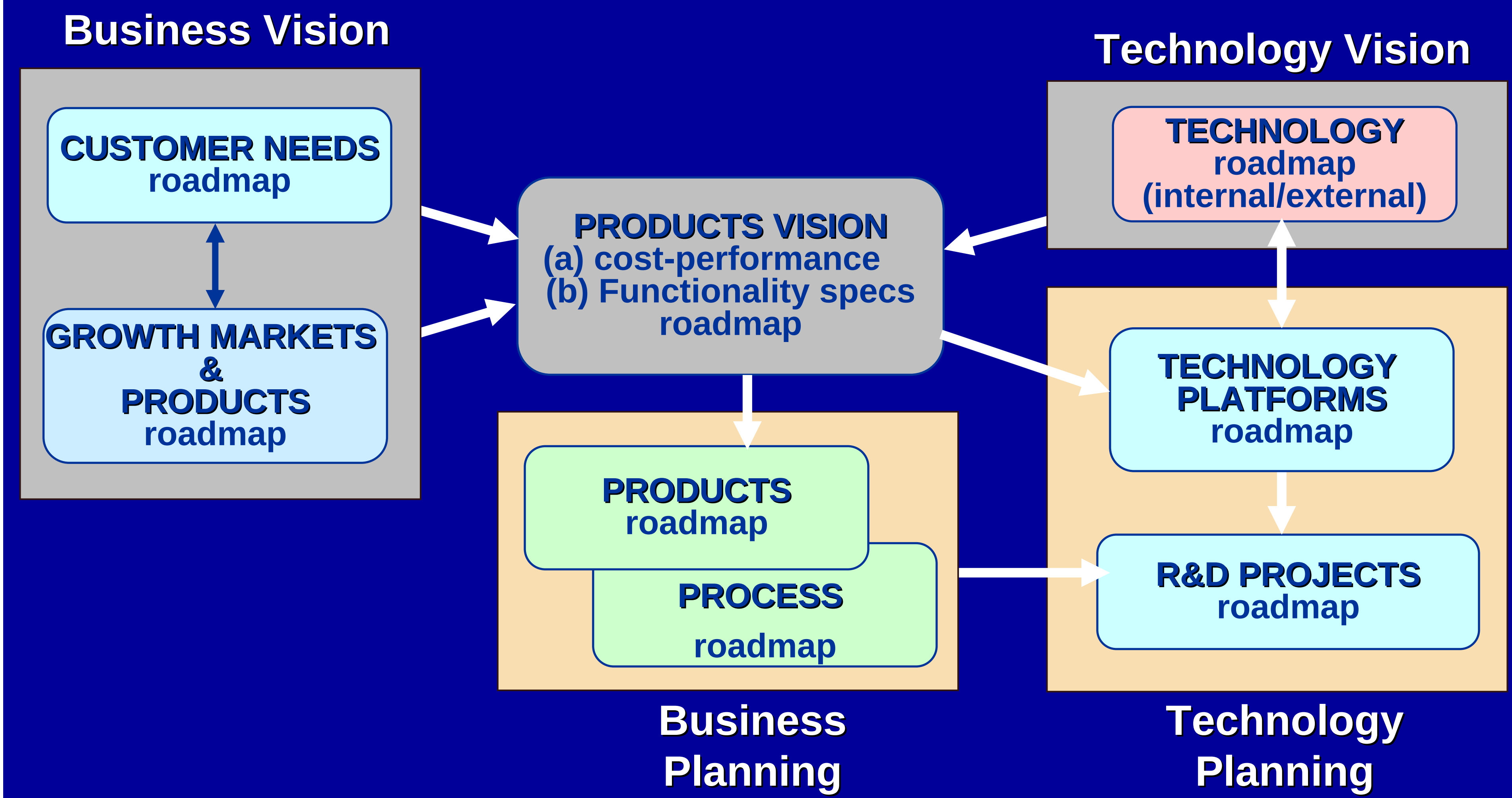
2. Align Business and R&D Vision and Strategies

Business Vision drives the Technology Vision: 60%



Technology Vision drives the Business Vision: 40%

Road-Maps: Linking Technology to Business



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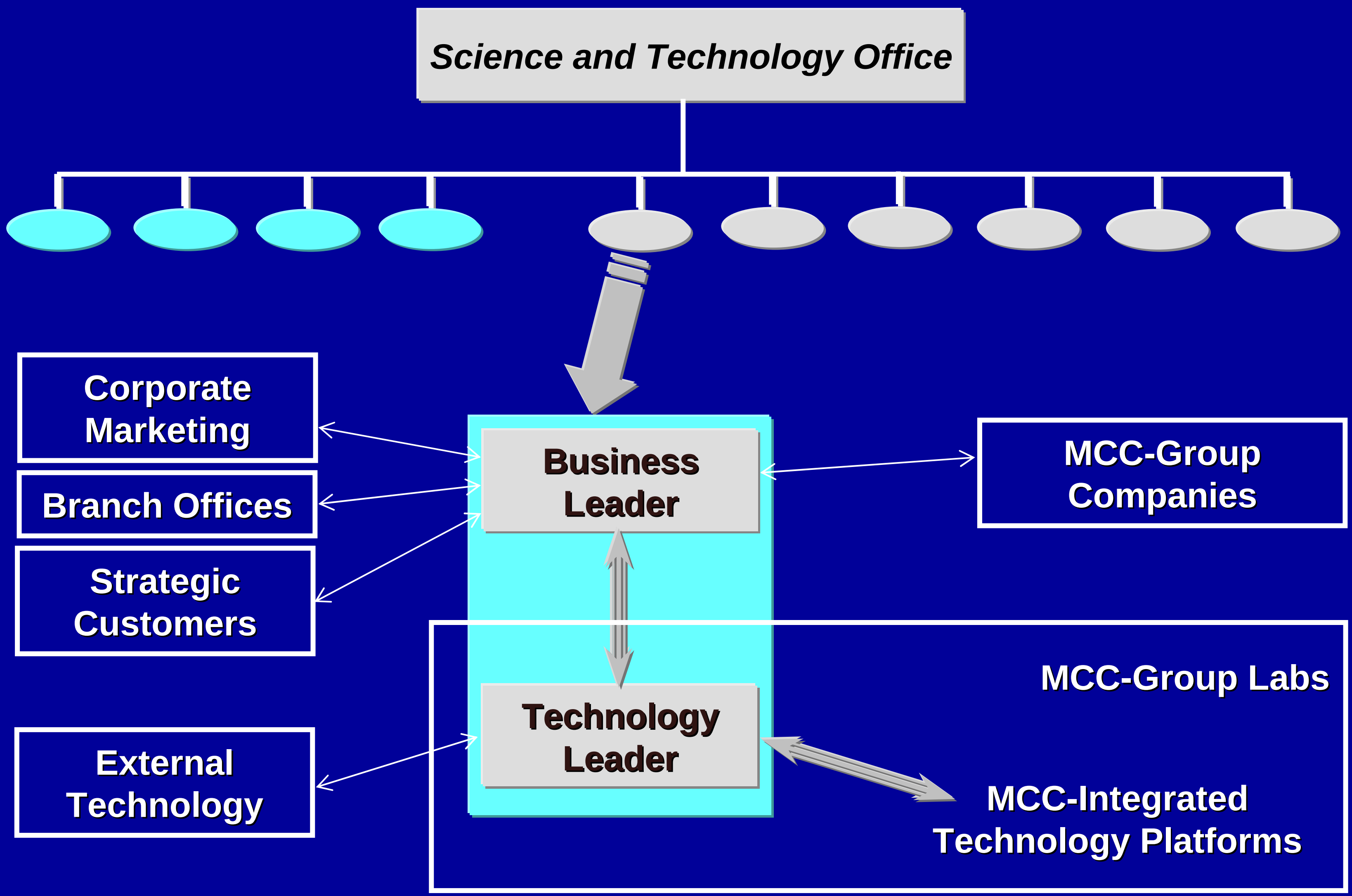
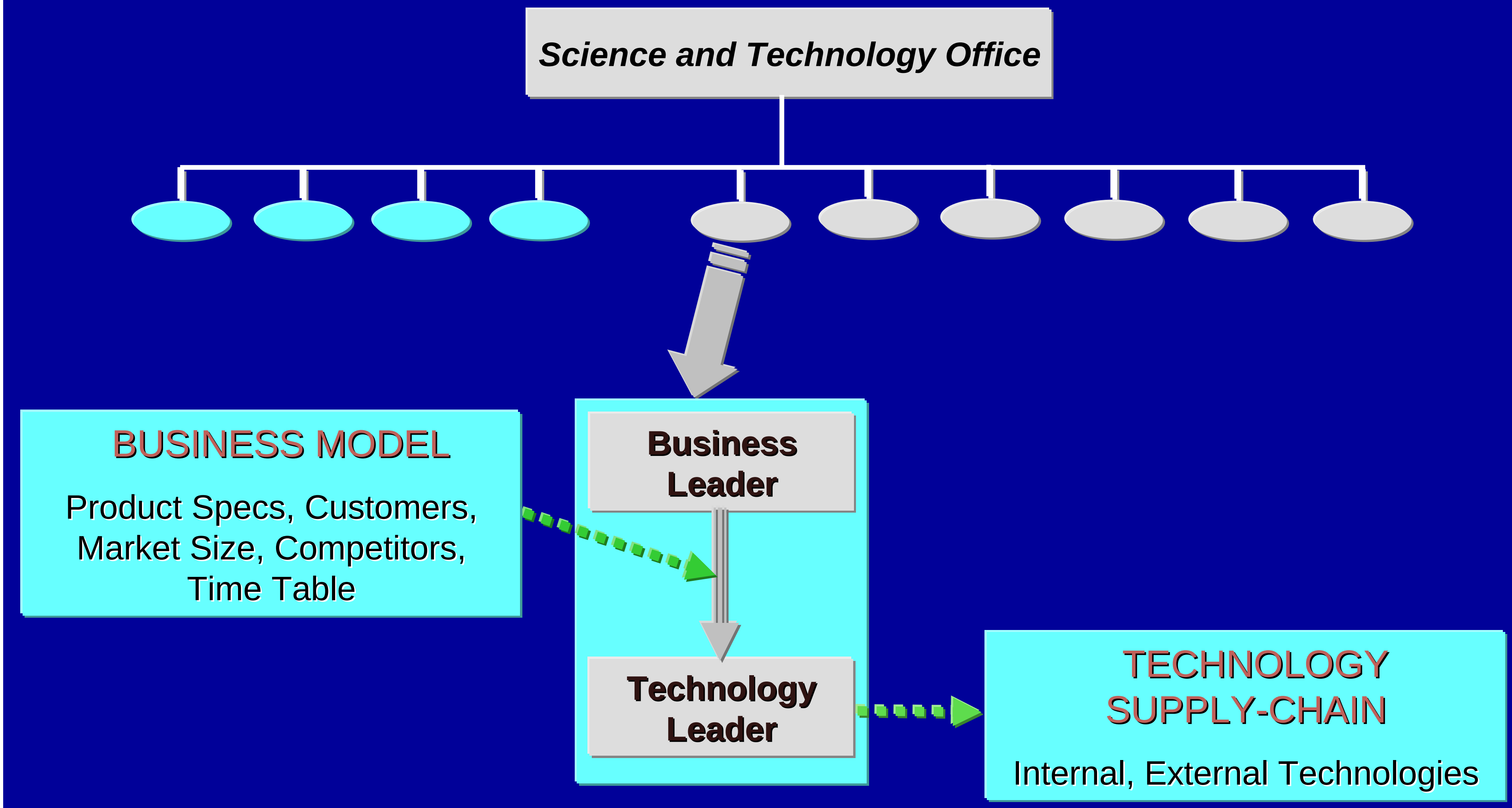
3. Integration of Marketing and R&D

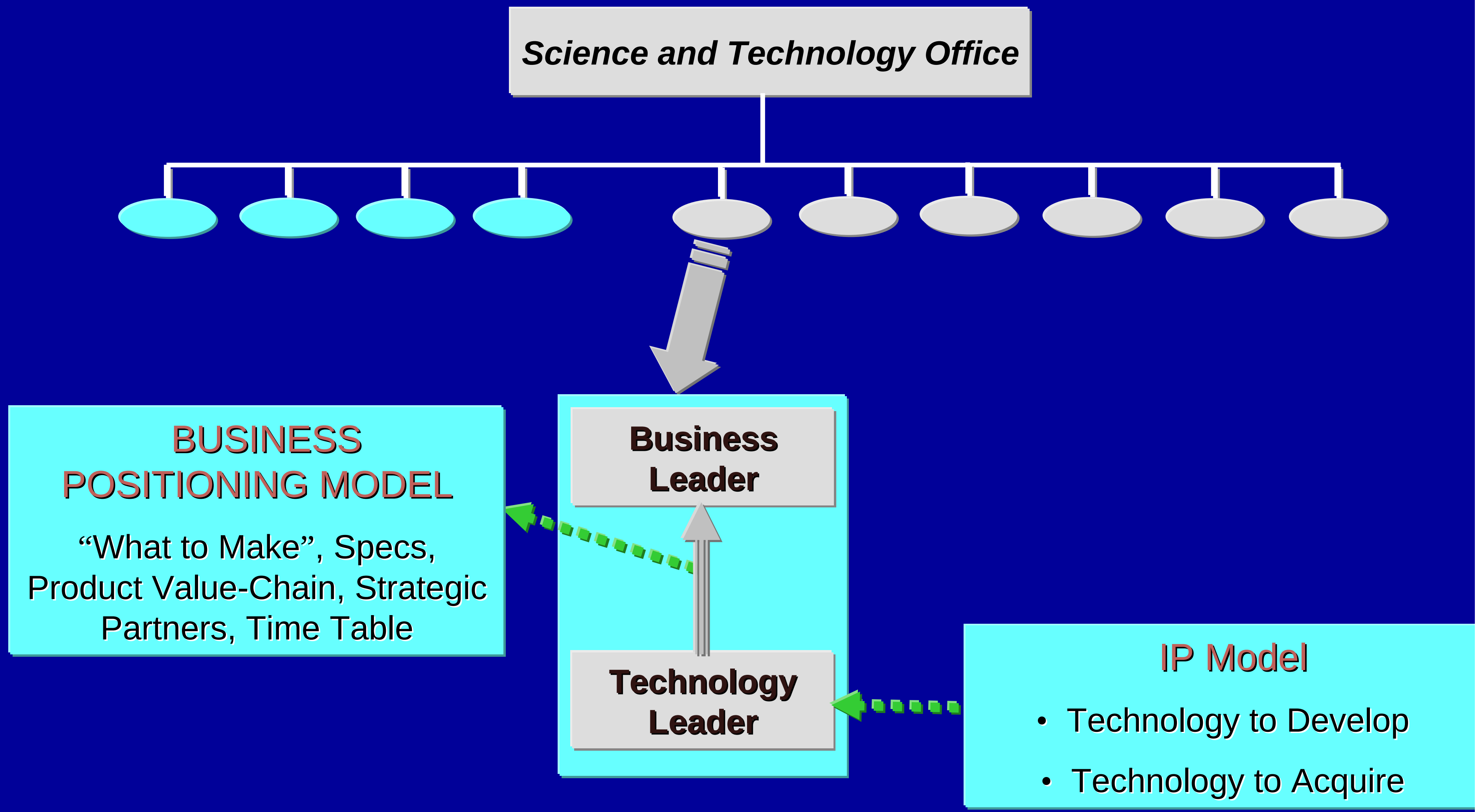
(Creating Small Entrepreneurial Groups)



3. Integration of Marketing and R&D: (Phase-1: Develop the Technology Supply-Chain)



3. Integration of Marketing and R&D: (Phase-2: Develop the Business Positioning Model)



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4. Leveraging Corporate Knowledge and Assets

- Exploratory Research in a Product-Centered Chemical Company is Inherently Very Risky, Costly
  - Explosion of New Scientific and Technological Developments
  - Inter-disciplinarity of High-Added Value Technological Platforms
  - Most of the New Ideas come from outside
  - Tackling all possibilities is "Economic Suicide"
  - Universities, National Labs, and Venture Start-Ups are natural partners
- Product-Development requires collaboration of interacting corporate partners in the Product-Chain
  - Strategic Alliances with Corporate Partners

4. Leveraging Corporate Knowledge and Assets (Examples)

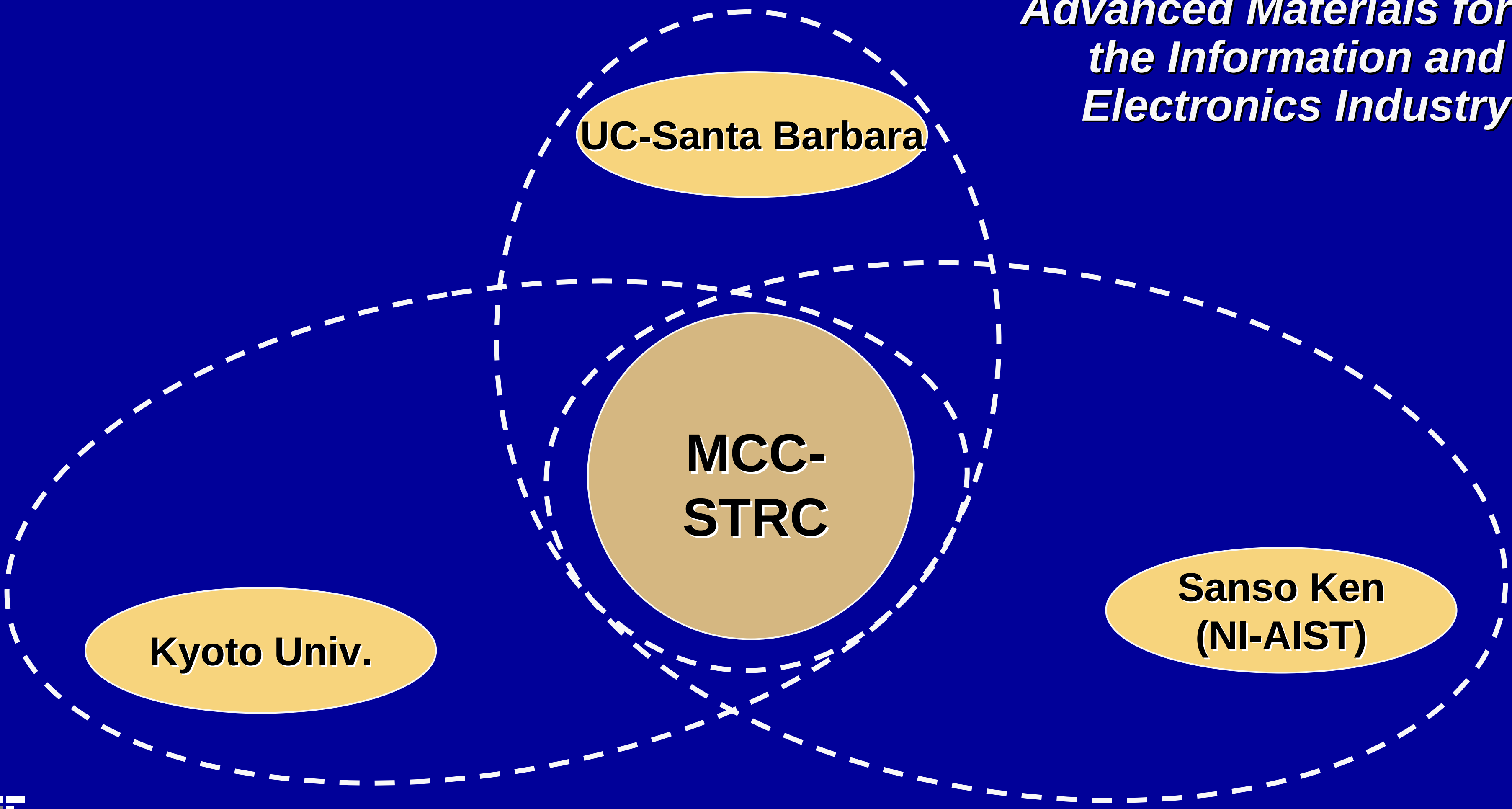
Corporate Alliances

- Ajinomoto: Biodegradable Polymers from Biomass
- Corporations X, Y, Z: Solid-State Lighting & Displays
- Corporations A, B: Materials for automobiles
- NTT, Hitachi, Rohm, Pioneer: Materials for the electronic and telecommunications devices
- 30 Corporations: Devices from Nano-Carbon Materials
- Corporations K,L: Materials and Fabrications for Diagnostic Devices
- Corporations I,J: Proteomics/Glycomics-based pharmaceuticals

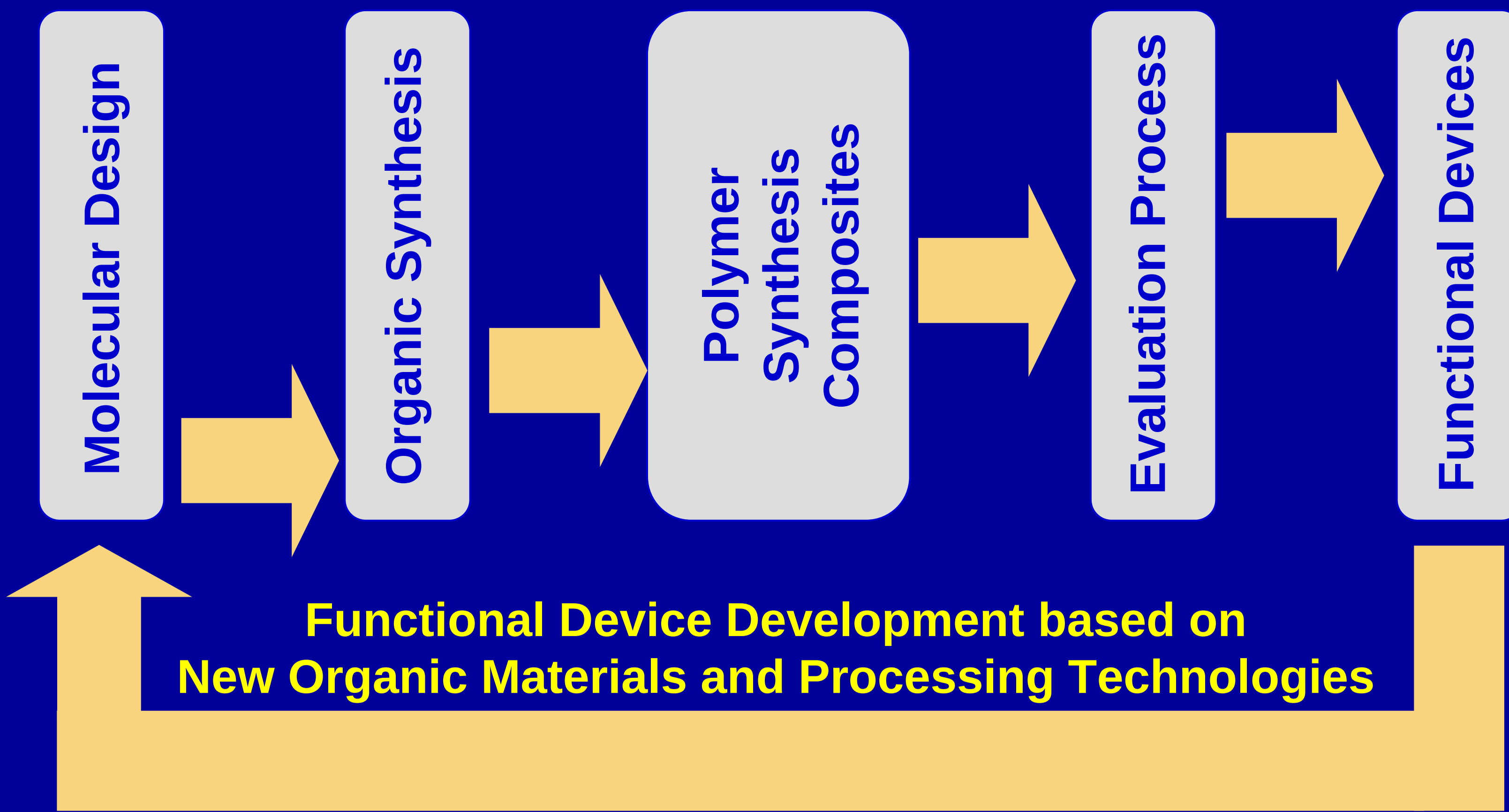
4. Leveraging Corporate Knowledge and Assets (Examples)

Academic Alliances

Advanced Materials for the Information and Electronics Industry



Cross-Company, Cross-Market Segment Vertical Integration at the Kyoto University Alliance



Corporate Alliances: OTFT

Organic TFT on Plastic Substrate (11/10/2002 Announce)

Advanced Technology Program, NIST (National Institute of Standards and Technology)

3 Years. DuPont expects to establish and commercialize for an OLED application by 2007.

DuPont	OLED, Flexible Substrate, Cost Effective Printing, OTFT
Sarnoff	Active Matrix TFT Design, Video Display Systems
Bell Labs	New Material, Design Process

Plastic Logics Inc.(a spin-out from Cambridge University's Cavendish Laboratory)

Organic transistor production by inkjet printing.

- Dow
- Seiko Epson
- Cambridge University

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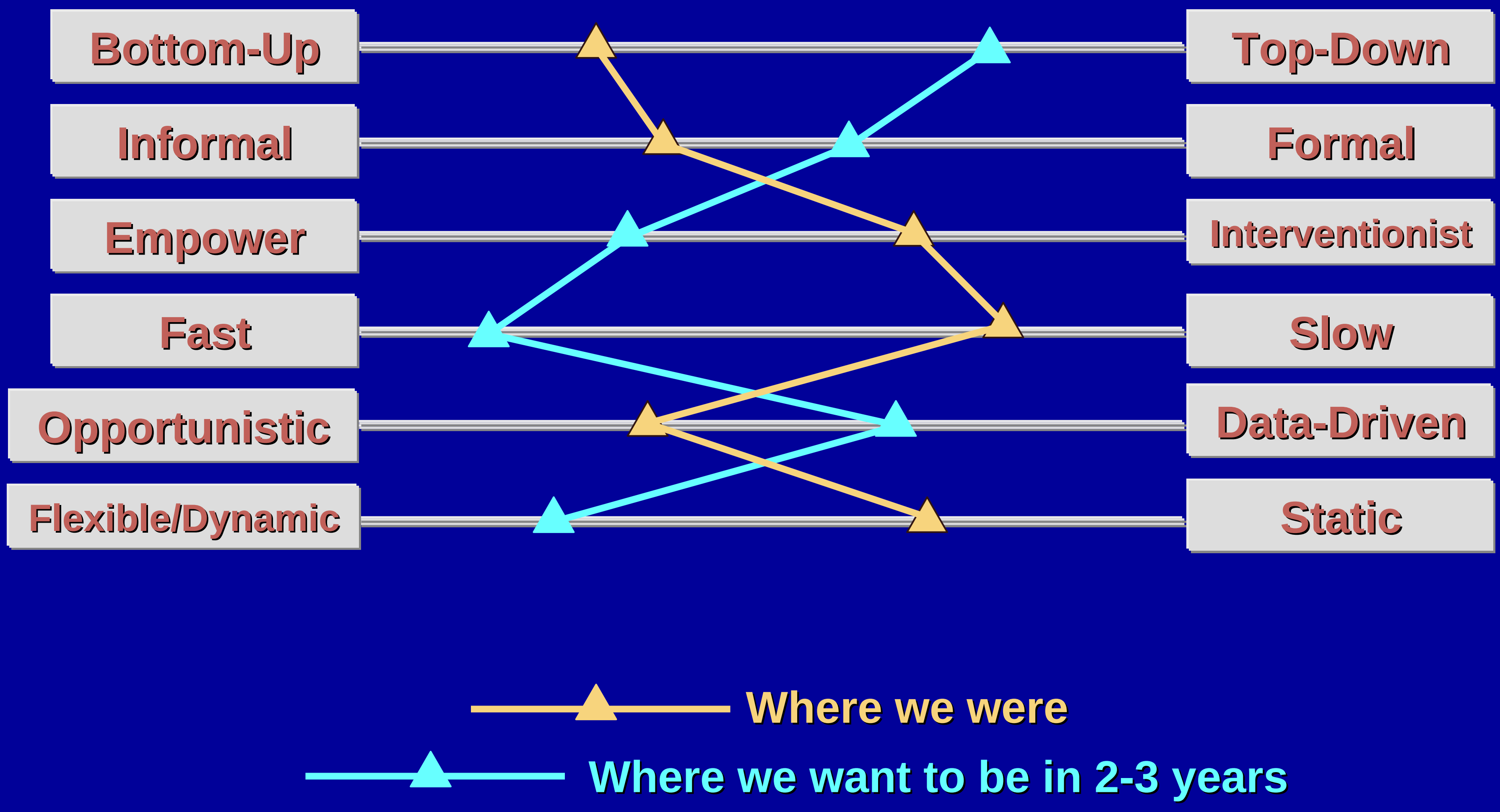
"What Do We Want to Become ? "



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Integrated Technology Platforms:
(Engines of Business Development)

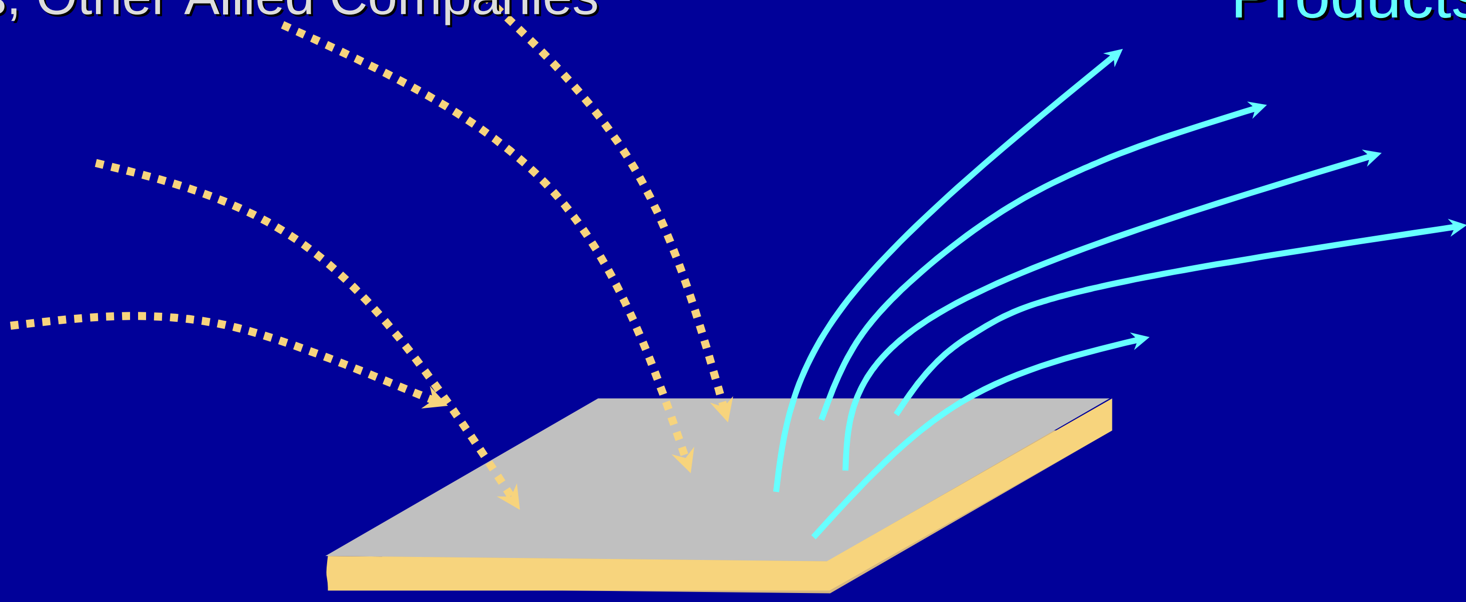
Technologies

- Internal

- External:

Universities, National Institutes,
Start-Ups, Other Allied Companies

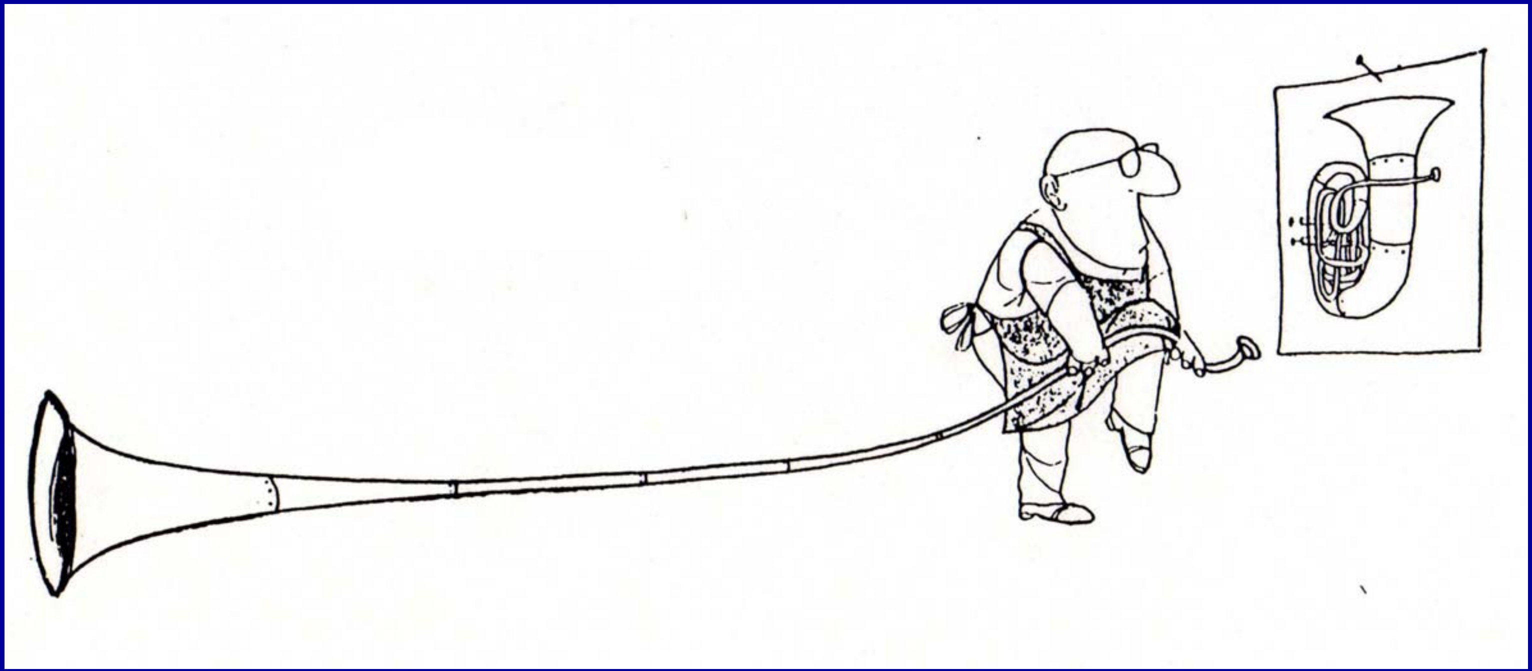
Products



Technology Platform

Part-6:

The Challenge for Academic Research in Chemical Engineering



" Chemical Engineering

as an

Educational Discipline

has ceased to exist on the

100th Anniversary of AIChE "

Reuters News Service, November 2008

1. *Knowledge as the Pivotal Element*

- A Product-Centered Chemical Company is a Company that Generates New and Manages effectively existing Knowledge
  - Scientific, Technological, Marketing, Social, Political, and other type of knowledge

- Is Chemical Engineering Research in academic institutions generating

  "Knowledge with Impact" ?

1. Knowledge as the Pivotal Element
(Academic Impact and Industrial IP)

"First-to-Patent not First-to-Market"
Coincidence of R&D and IP Strategies

- ❖ Analysis of 500 industrial patents (1996-2002)
  - 4 US Chemical Companies;
  - High index of scientific cutting edge patents (MIT index)
  - Chemicals, Materials, Product and Process patents
- ❖ Citations of academic research:
  - 19 % of citations were academic research papers
  - Only 0.3% of citations were from Chemical Engineering published research papers.

1. Knowledge as the Pivotal Element (Academic Impact and Industrial IP)

- Patent Productivity of Academic Research
  - 5 chemical engineering departments
  - 4 chemistry departments
  - 3 departments of materials sciences
  - Period: 1976-2002
- Productivity (no. of patents/faculty, year)
  - Materials Science = 0.3 – 0.4
  - Chemistry = 0.2 – 0.3
  - Chemical Engineering = 0.08 – 1.2

(One dept = 0.25)

2. The "Hidden Cost" of Research

A List of Industrial, Truly Difficult, Technological Problems Exists

↓

Who Is Working on Solving them ?

Is the academic world ready to "listen" (really) to the exciting industrial challenges and try to have an impact in addressing them?

3. *Inter-Disciplinary Research*

- Who is going to teach us how to do it?
  - "Inter-disciplinary" research is more than "collaborative" research
  - Crossing disciplinary segments, with tangible impact, is not yet visible
- Who is going to show us how to assign IP rights in inter-disciplinary research?
  - Serious handicap

4. PSE in a Product-Centered Industry

- Many “Products” are Processes in themselves. Why has Process Systems Engineering missed the chance to lead the engineering and manufacturing of such systems?
- Is PSE prepared to teach us how to engineer (design and manufacture) products, or should someone else do it?
  - The experience of discrete-parts’ product design and manufacturing (Mechanical Engineering)

5. Future

The Product-Oriented Character of the Chemical Industry

is the best chance for Academic Chemical Engineering

to become

Engineering

again

I suspect that the young of researchers of AIChE 20 are instinctively following this path

Part-6:

Summary and an Exhortation

Summary

- Chemical companies are becoming progressively more "Product-and-Service Centered".
- This shift requires a profound change in their "Corporate Culture" and "Operational Style", and they are ill-prepared for it.
- Academic Chemical Engineering is also ill-equipped to address the new educational and research needs.
- The "War for Talent" will be very fierce and will determine winners and losers.

An Exhortation

(Paraphrasing Roger Sargent)

My address …was frankly an exhortation, and today, perhaps in keeping with the general mood of our profession,

it is a clear warning:

If we don't follow the dictates of our times and set about building the

Product-Centered future of Chemical Engineering,

as an

Engineering Discipline

again,

soon we are not going to have one!

"Is there a future for chemical engineering?", R. Sargent, 1977.